Preliminary Astrometric Results from the PS1 Demo Month and Routine Survey Operations

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ABSTRACT

Pan-STARRS PS1 has transitioned from its development phase to its operational phase. In March 2010, the Demo Month used a special cadence to allow data exploration to start. In May 2010, the Operation Phase commenced. Although there have been occasional breaks and revisions, routine data collection has been maintained. So far, more than 16,000 frames are available to the PS1 Consortium for analysis. Based on these first few frames, the provisional astrometric results show the error for a single measure of a well-exposed star to be about 15 to 20 milliarcsec.

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1) Survey Operations:

The Pan-STARRS PS1 survey began its Operational phase in May 2010. Since then, there have been minor interruptions but the survey has been taking large amounts of very high quality data. The cadence optimizes sky coverage in multiple survey colors (SDSS *g-,r-,i-,z-,y*-bands) at the expense of repeated visits to the same field. The current sky coverage map shows this. Using a pseudo-color representation of the filters, Figure 1 shows the current sky coverage based on 16,747 full-camera observations (60 Orthogonal Transfer CCD images each) transferred to the U.S. Naval Observatory Flagstaff Station (NOFS) so far. More frames have been taken, and this count does not include observations taken prior to the Demo Month.
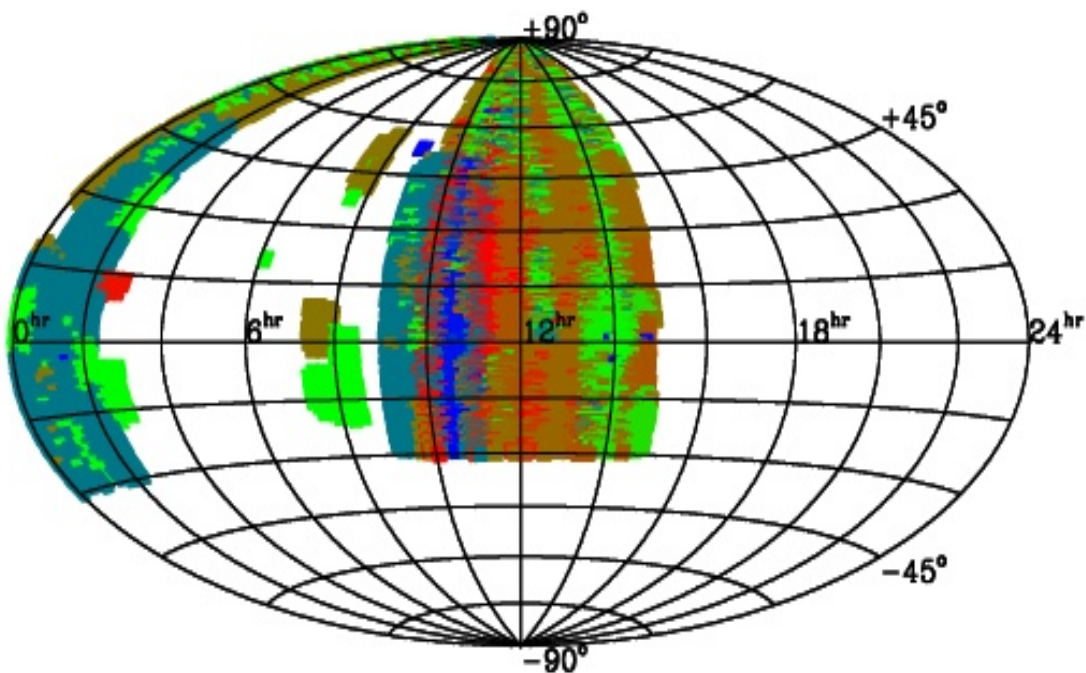
Figure 1: PS1 sky coverage as of September 1, 2010.

2. Correlation With Stars In Other Catalogs:

The PS1 Image Processing Pipeline [2] (IPP) correlates the images detected on each frame with the 2MASS catalog [3] to produce preliminary astrometric solutions. Using these coordinates, the NOFS astrometric pipeline correlates PS1 objects with other catalogs (USNO-B1.0, SDSS, Tycho-2, 2MASS, etc.) so that unique star identification numbers can be assigned across all catalogs. This correlation is done in two steps. The first step uses a 1.0 arcsec radius, and when completed the correlated PS1 observations and their reference catalog counterparts are removed from the lists. The second step uses a 10.0 arcsec radius. Figure 2 shows the number of correlations as a function of radius for the 345,264,598 PS1 objects with counterparts in other catalogs.
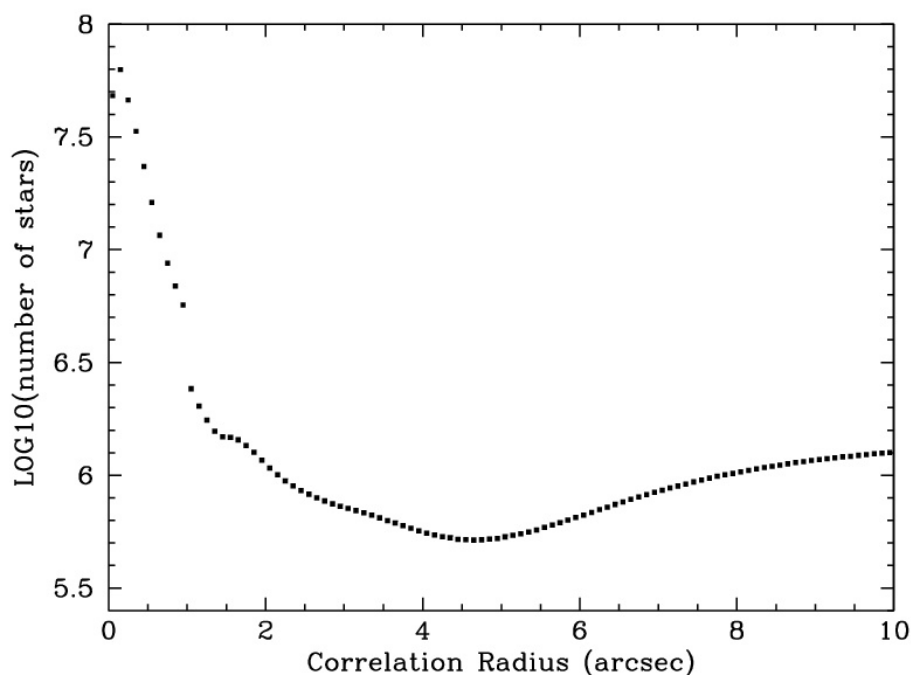

Figure 2. Number of correlations as a function of radius.

Figure 2 is interpreted in the following manner. The initial steep decline is the astrometric error for each correlated pair, and the standard deviation for these pairings is about 0.3 arcsec. Whereas the 2MASS catalog error for a brighter star is believed to be in the range of 0.07 to 0.10 arcsec, the luminosity function has more stars at fainter magnitudes where the astrometric error is larger due to simple photon statistics. Also, many PS1 stars do not appear in the 2MASS catalog, and the astrometric error of the USNO-B1.0 catalog is believed to be in the range of 0.2 to 0.3 arcsec. Hence, the astrometric error for the typical IPP coordinate is probably in the range of 0.1 to 0.2 arcsec depending on brightness. The break at 1.0 arcsec arises from the two-part nature of the search. The change of slope and structure between about 1 and 5 arcsec is interpreted as the detection of true stellar proper motions. The change of slope and slow rise in the number of correlations for radii larger than 5 arcsec are interpreted as effects of spurious correlations: there should be a very few true proper motion stars with such motions. These stars would be quite exciting to find, but are very difficult to confirm.

3) Astrometric Solutions:

The NOFS astrometric pipeline was designed to deal with large quantities of high quality data, but it faces many serious challenges. The PS1 cadence includes dithers of the telescope boresight and deliberate rotations of the camera with respect to the telescope in addition to the natural rotation associated with an alt-azimuth telescope design.

Hence, the HEALPix[4] tessellation scheme was adopted, and *side*=64 was used for the data storage strategy and *side*=256 was used for the individual astrometric solutions. A great deal of bookkeeping is needed to identify which OTCCD of which observation measured stars in a specific HEALPix. In many cases, each HEALPix is spread over several OTCCDs. A separate astrometric solution is needed for each OTCCD for each observation for each HEALPix. So far, there are multi-epoch PS1 observations in 335,231 *side*=256 HEALPix.

Interpretation of the ensemble of HEALPix solutions is made more complicated by several factors. Perhaps the most important is the current inability of the NOFS pipeline to compute and incorporate the weights appropriate for a particular observation. Effects such as seeing, sky background, focus, and wind should be incorporated into the weights, but at the moment all observations are assigned unit weight. Another significant problem is the very preliminary nature of the algorithm designed to sense and remove statistical outliers. There are many reasons why the measured position could be in error, but without a reliable master catalog it is quite difficult to sense these in the ensemble of measures. Also, the effects of differential color refraction (DCR) should displace the observed positions as a function of star color and the circumstances of the observation. Again, the lack of a master catalog makes it difficult to fit such terms. With these caveats, statistics from the analysis of about 9,700 well-observed HEALPix are shown in Figure 3.
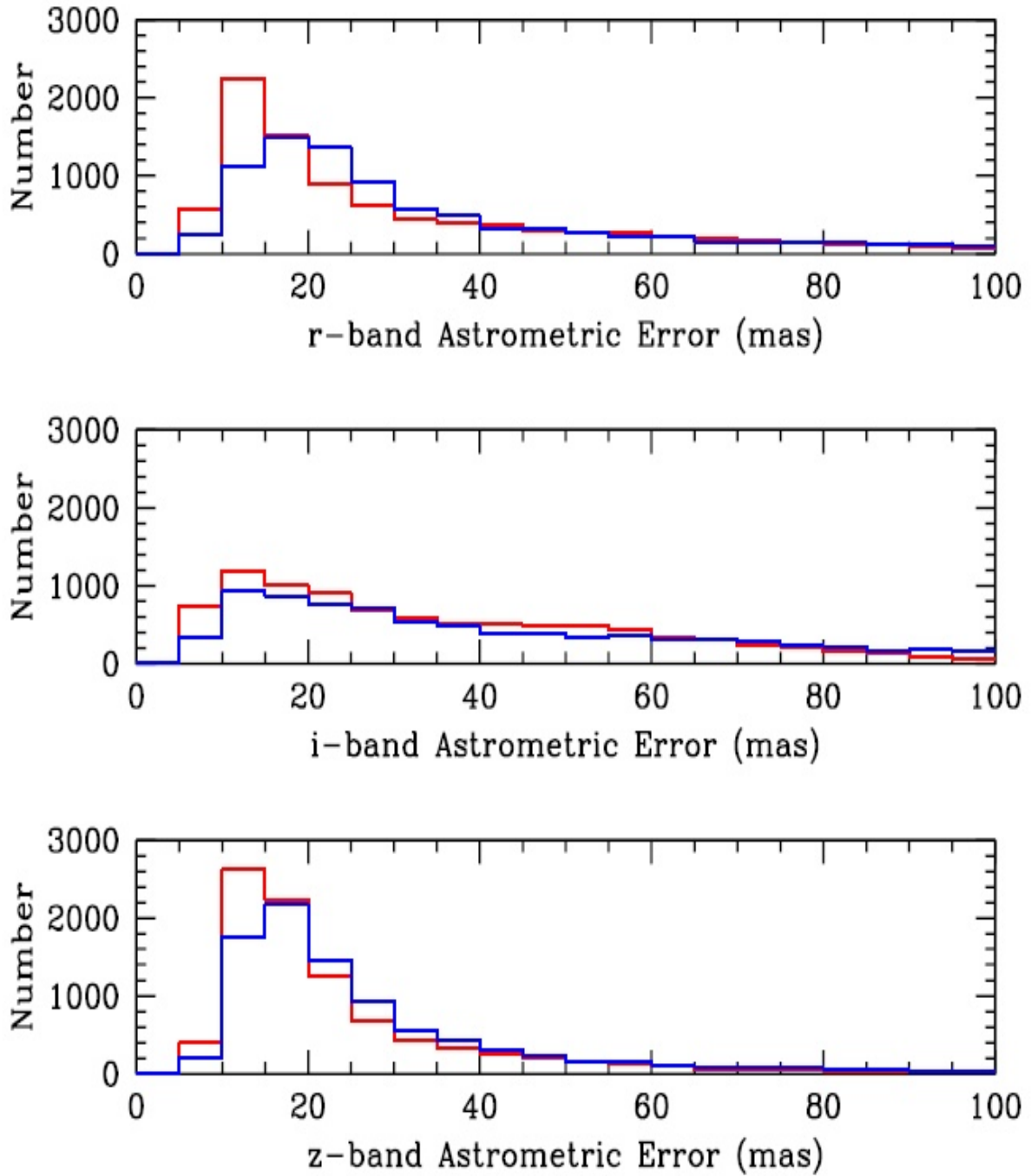
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[4] http://healpix.jpl.nasa.gov

Figure 3: Astrometric error distributions in (in milliarcsec) for single color solutions in *side*=256 HEALPix with PS1 observational epochs covering more than 30 days. The red lines are from the ξ (RA) solutions and the blue are from η (Dec) solutions.

In spite of all of the difficulties mentioned above, it seems reasonable to conclude that under good circumstances (whatever this really means) that a single measure of a well exposed stellar image has an astrometric error between 15 and 20 milliarcsec (mas) in each coordinate. The long tails shown in Figure 3 are interpreted as being the results of the inadequate trimming of statistical outliers and the incomplete astrometric model. The solutions shown in Figure 3 include only an Affine transformation between the OTCCD (column,row) and tangent plane coordinates (ξ,η). The size of a *side*=256 HEALPix is about 14 arcmin on a side, but there may be significant focal plane curvature over this size, particularly near the edge of the field of view. The impacts of DCR are still unknown.

4) Conclusions:

The results presented here are quite preliminary, and reflect the mis-match between the task to be done and the level of effort available. However, the results presented in Figure 3 offer some hope that the astrometric error of a single observation is between 15 and 20 mas. This is about a factor of 2 worse than the pre-survey predictions, but much work remains to be done. The most important areas for software development are weights computed from the metadata , an improved algorithm for sensing and removing statistical outliers, and the removal of the effects of DCR.

It is DGM's pleasure to thank the members of the PS1 Project and Consortium teams. This is an amazing project!